PBL Project 2

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% Code Contributors:
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% Felix Wang        Last Commit: 10/21/2025

% Overview
% ----------------------------
% ACCOUNTING EQUATION: Ψ_out = Ψ_in [1 - w_reabs + w_sec]

% ASSUMPTIONS:
% (1) Steady-State
% (2) No Reactions
% (3) No Leaks

% LIMITATIONS:
% (1) Water flow held constant (no ADH modulation)
% (2) Active/passive Transport not explicitly modeled
% (3) Tubuloglomerular feedback not included

% OUTPUTS:
% > Model allows for various scenarios
% (1) Mass flow rate of each chemical constituent in each unit
% (2) Concentration of each chemical constituent in each unit


% Kidney Model
% ----------------------------
function[molar_flow_rates, concs, grams_per_min_out] = kidney_model(C0,
snGFR, condition)

% Indices
% ----------------------------
% Nephronal Units (x-Axis)
units = ["RC", "PT(S1)", "PT(S2)", "PT(S3)", "DL", "AL", "DT", "CD"];
% RC = Renal Corpuscle
% PT = Proximal Tubule: Split into S1, S2, S3
% DL = Descending Limb
% AL = Ascending Limb
% DT = Distal Tubule
% CD = Collecting Duct

% Chemical Constituents (y-Axis)
chemicals = ["Na^+", "Cl^-", "Urea", "Glucose", "K^+", "HCO_3^-", "Mg^{2+}",
"PO_4^{3-}", "Creatinine", "Ca^{2+}"];
colors = ["#012966", "#005f73", "#0a9396", "#94d2bd", "#e9d8a6", "#ee9b00",
"#ca6702", "#bb3e03", "#ae2012", "#9b2226"];
molec_weights = [22.989, 35.453, 60.056, 180.156, 39.098, 61.020, 24.305,
```

```
94.971, 113.12, 40.08]; % g/mol

% Matrix Lengths
nSeg = length(units);
nSol = length(chemicals);


% Input Data Matrices
% ---------------------------
% Fractions derived from a host of literature sources, primarily:
% - Weinstein, A. M. Seldin and Giebisch's The Kidney. Elsevier Inc., 2008.
849-887.1081-1142
% - Vallon, V. Am J Physiol Cell Physiol. 2011 Jan; 300(1): C6-C8.
% - Oregon State University, open courseware

%{
      Na+     Cl-    Urea    Gluc     K+     HCO3-   Mg2+    PO4^3-
Creat    Ca2+
RC | (1,1) | (1,2) | (1,3) | (1,4) | (1,5) | (1,6) | (1,7) | (1,8) | (1,9) |
(1,10)
S1 | (2,1) | (2,2) | (2,3) | (2,4) | (2,5) | (2,6) | (2,7) | (2,8) | (2,9) |
(2,10)
S2 | (3,1) | (3,2) | (3,3) | (3,4) | (3,5) | (3,6) | (3,7) | (3,8) | (3,9) |
(3,10)
S3 | (4,1) | (4,2) | (4,3) | (4,4) | (4,5) | (4,6) | (4,7) | (4,8) | (4,9) |
(4,10)
DL | (5,1) | (5,2) | (5,3) | (5,4) | (5,5) | (5,6) | (5,7) | (5,8) | (5,9) |
(5,10)
AL | (6,1) | (6,2) | (6,3) | (6,4) | (6,5) | (6,6) | (6,7) | (6,8) | (6,9) |
(6,10)
DT | (7,1) | (7,2) | (7,3) | (7,4) | (7,5) | (7,6) | (7,7) | (7,8) | (7,9) |
(7,10)
CD | (8,1) | (8,2) | (8,3) | (8,4) | (8,5) | (8,6) | (8,7) | (8,8) | (8,9) |
(8,10)
%}

% Reabsorption Fractions per Constituent (of incoming stream) per Unit
% This is what's returned to the interstitial fluid
% Solutes     Na+,     Cl-,     Urea,    Glucose, K+,      HCO3-,   Mg2+,
PO4^3-,  Creat,   Ca2+
reabs_frac = [0,       0,       0,       0,       0,       0,       0,
0,       0,       0;    % RC
              0.33,    0.33,    0,       0.90,    0,       0.80,    0,
0.35,    0,       0.35; % PT(S1)
              0.328,   0.328,   0,       0.09,    0,       0.10,    0,
0.25,    0,       0.25; % PT(S2)
              0.222,   0.222,   0.50,    0,       0.60,    0,       0.20,
0.10,    0,       0.10; % PT(S3)
              0,       0,       0,       0,       0,       0.15,    0,
0,       0,       0;    % DL
              0.25,    0.25,    0,       0,       0.25,    0,       0.7,
0,       0,       0.20; % AL
              0.05,    0.05,    0,       0,       0,       0.05,    0.05,
0.05,    0,       0.10; % DT
```

```
              0,       0,       0,       0,       0,       0,       0,
0,       0,       0.05; % CD
             ];
%{
 • Note: Na/Cl reabsorption can increase to 0.02/0.03 in the Collecting Duct
when producing dilute urine (over-hydration) or with high salt intake (need
to dilute urine)
 • Note: Urea is reabsorbed when producing concentrated urine to conserve
water, as urea establishes an osmotic gradient (dehydration)
 • However, because urea reabsorption is tightly regulated by ADH and other
hormones, this is outside the scope of this model
%}

% Secretion Fractions per Constituent (of incoming stream) per Unit
% This is what's secreted by the bloodstream into tubules post-RC (initial
filtration)
% Solutes    Na+,     Cl-,     Urea,    Glucose, K+,      HCO3-,    Mg2+,
PO4^3-,  Creat,   Ca2+
sec_frac =   [0,       0,       0,       0,       0,       0,       0,
0,       0,       0;    % RC
              0,       0,       0,       0,       0,       0,       0,
0,       0,       0;    % PT(S1)
              0,       0,       0,       0,       0,       0,       0,
0,       0.30,    0;    % PT(S2)
              0,       0,       0,       0,       0,       0,       0,
0,       0,       0;    % PT(S3)
              0,       0,       0.15,    0,       0,       0,       0,
0,       0,       0;    % DL
              0,       0,       0,       0,       0,       0,       0,
0,       0,       0;    % AL
              0,       0,       0,       0,       0.10,    0,       0,
0,       0,       0;    % DT
              0,       0,       0,       0,       0.10,    0,       0,
0,       0,       0;    % CD
              ];

% Safety Clamps
reabs_frac = max(0, min(reabs_frac, 0.999));
sec_frac = max(0, min(sec_frac, 0.999));


% Calculated Data Matrices
% ----------------------------
% Molar Flow Rates per Constituent per Unit
molar_flow_rates = zeros(nSeg,nSol); % mmol/min

% Mass Flow Rates per Constituent leaving Collecting Duct (Outlet)
grams_per_min_out = zeros(1,nSol); % g/min

% Concentrations per Constituent per Unit
concs = zeros(nSeg,nSol); % mmol/L = mM

% Volumetric flow rates per constituent per unit
vol_flow_rates = snGFR * ones(nSeg,1); % mL/min
```

```
% Input Parameters
% ----------------------------
% Initializes input stream (C0 & snGFR) to Renal Corpuscle
%{
 molar_flow_rates = vol_flow_rates * concs
 mmol/min         = mL/min * mM * 1L/1000mL
%}

concs(1,:) = C0; % mmol/L = mM
molar_flow_rates(1,:) = snGFR .* concs(1,:) * 1e-3; % mmol/min


% Adjustments
% ----------------------------
% Adjusts secretion fractions in the Collecting Duct for Na+ in the event of
high salt intake
if concs(1,1) > 140 && concs(1,2) > 106
      sec_frac(8,1) = 0.02;  % Na+
      sec_frac(8,2) = 0.03;  % Cl-
end


% Calculations
% ----------------------------
% Calculates molar flow rates and concentrations for each unit
for i = 2:nSeg
    % Accounting for Each Constituent
    N_in  = molar_flow_rates(i-1,:); % Vector with inflows for all
constituents
    N_out = N_in .* (1 - reabs_frac(i,:) + sec_frac(i,:)); % Vector with
outflows for all constituents

    if any(N_out < 0)
        errordlg("Negative Flow Rate at Row " + i + "!!!") % Error Warning
    end

    % Populates row i of Data Matrix
    molar_flow_rates(i,:) = N_out; % mmol/min
    concs(i,:) = molar_flow_rates(i,:) ./ vol_flow_rates(i); % mmol/min /
mL/min = mmol/L
end

% Converts outlet molar flow rates to mass flow rates
for j = 1:nSol
    grams_per_min_out(j) = molar_flow_rates(end,j) * molec_weights(j) *
1e-3; % mmol/min * g/mol * 1e-3 = g/min
end


% Print
% ----------------------------
% Molar Flow Rates
```

```
fprintf("\n\n" + condition + "\n-------------------------\n");

fprintf("8x10 Molar Flow Rate Matrix\n" + ...
    "• Rows = RC, S1, S2, S3, DL, AL, DT, CD\n" + ...
    "• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-,
Creatinine, Ca2+");
disp(molar_flow_rates);

% Concentrations
fprintf("8x10 Concentrations Matrix\n" + ...
    "• Rows = RC, S1, S2, S3, DL, AL, DT, CD\n" + ...
    "• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-,
Creatinine, Ca2+");
disp(concs);

% Outlet Mass Flow Rates
disp("Outlet (collecting duct) in grams/min per solute: ");
for k = 1:nSol
    disp(chemicals(k) + ": " + num2str(grams_per_min_out(k)));
end


% Graphs
% ----------------------------
fig = figure('Name', condition, 'Units', 'normalized', 'Position', [0.05
0.05 0.9 0.8]);

% Adds tabs to figure
tabGroup = uitabgroup(fig);
tab1 = uitab(tabGroup, 'Title', 'Concentrations');
tab2 = uitab(tabGroup, 'Title', 'Molar Flow Rates');
tab3 = uitab(tabGroup, 'Title', 'Outlet Mass Flow Rates');

% Display layout for graphs
tLayout1 = tiledlayout(tab1, 2, 5, 'TileSpacing', 'compact', 'Padding',
'compact');
tLayout2 = tiledlayout(tab2, 2, 5, 'TileSpacing', 'compact', 'Padding',
'compact');

% Figure 1: Concentrations
for k = 1:nSol
    ax1 = nexttile(tLayout1);
    plot(ax1, 1:nSeg, concs(:,k), '-', 'Color', colors(k), 'LineWidth', 2);
    grid on
    title(chemicals(k) + " Concentration", 'FontWeight','bold', 'FontSize',
12)
    xticks(1:nSeg)
    xticklabels(units)
    ylabel('mM')
    ylim([0 inf])
end
sgtitle({"Solute Concentrations Along Nephron Segments", "Test Case: " +
condition}, 'FontSize', 14, 'FontWeight','bold')
```

```
% Figure 2: Molar Flow Rates
for k = 1:nSol
    ax2 = nexttile(tLayout2);
    plot(ax2, 1:nSeg, molar_flow_rates(:,k), '-', 'Color', colors(k),
'LineWidth', 2);
    grid on
    title(chemicals(k) + " Molar Flow", 'FontWeight','bold', 'FontSize', 12)
    xticks(1:nSeg)
    xticklabels(units)
    ylabel('mmol/min')
    ylim([0 inf])
end
sgtitle({"Molar Flow Rates Along Nephron Segments", "Test Case: " +
condition}, 'FontSize', 14, 'FontWeight','bold')

% Figure 3: Outlet Mass Flow Rates
axes('Parent', tab3);
b = bar(1:nSol, grams_per_min_out);
b.FaceColor = 'flat';
for k = 1:nSol
    b.CData(k,:) = hex2rgb(colors(k));
end
grid on
xticks(1:nSol)
xticklabels(chemicals)
ylabel('g/min')
ylim([0 inf])
sgtitle({"Outlet Mass Flow Rates Along Nephron Segments", "Test Case: " +
condition}, 'FontSize', 14, 'FontWeight','bold')

end

% Test Cases
% ----------------------------
function[conc_out, snGFR_out] = test_cases(C0, snGFR, condition)
% Implements test cases by adjusting inlet concentrations and single-nephron
GFR accordingly
% Test Cases: 'healthy',
%             'ckd3b' (CKD, stage 3b),
%             't2dm_early' (early type 2 diabetes),
%             't2dm_late' (late type 2 diabetes),
%             'htn' (hypertension)

% Re-indexing for convenience
Na = 1;
Cl = 2;
Urea = 3;
Gluc = 4;
K = 5;
HCO3 = 6;
Mg = 7;
PO4 = 8;
Creat = 9;
Ca = 10;
```

```
switch lower(condition)
    case 'healthy'
        % No change, using base values

    case 'ckd3b'
        % We are modeling stage 3b as this marks substantial loss of kidney
function and sure-fire diagnosis of CKD

        % Normal GFR = 90-120 mL/min; Stage 3b GFR = 30-44 mL/min
        % Scaling factor as reference as snGFR values not available
        snGFR = snGFR * 37/105; % Using a scaling factor as reference as
snGFR values not available

        % Creatinine level increased by 60%
        % Typical creatinine level: 0.7-1.3 mg/dL in males, 0.6-1.1 mg/dL in
females
        % CKD3b creatinine level: 1.2-2.0 mg/dL in males, 1.8-3.0 mg/dL in
females
        % 50-70% increase
        C0(Creat) = C0(Creat) * 1.6;

        % Urea level increased by 40% (estimate)
        C0(Urea) = C0(Urea) * 1.4;

        % Potassium level increased by 15% (estimate; hyperkalemia)
        C0(K) = C0(K) * 1.15;

        % Phosphate level increased by 25% (estimate; due to degradation of
phosphate secretion)
        C0(PO4) = C0(PO4) * 1.25;

        % Bicarbonate level decreased, not significantly (sign of metabolic
acidosis)
        C0(HCO3) = C0(HCO3) * 0.90;

        % Calcium level decreased, not significantly (sign of hypocalcemia)
        C0(Ca) = C0(Ca) * 0.90;

    case 't2dm_early'
        % Separating early and late stages because early T2DM =
hyperfiltration

        % Normal GFR = 120 mL/min; Early T2DM GFR = 120-150 mL/min, median
at 135 mL/min
        % Approximating hyperfiltration
        snGFR = snGFR * 1.125;

        % Average plasma concentration of glucose during early hyperglycemia
        C0(Gluc) = 7; % 7 mmol/L = 126 mg/dL

    case 't2dm_late'
        % Separating early and late stages because late T2DM = hypofiltration
```

```
        % Normal GFR = 90-120 mL/min; Late T2DM GFR = 15-29 mL/min, median
at 22 mL/min (correlated with Stage 4-5 CKD)
        % Approximating hypofiltration
        snGFR = snGFR * 22/105;

        % Average plasma concentration of glucose during late stage
hyperglycemia
        C0(Gluc) = 9.7; % 8.3-11.1 mmol/L

        % Potassium level jumps to greater than 6 mmol/L
        C0(K) = C0(K) * 1.30; % Jumps to greater than 6 mmol/L

        % Phosphate level jumps to greater than 1.5 mmol/L
        C0(PO4) = C0(PO4) * 1.15; % Jumps to greater than 1.5 mmol/L

        % Bicarbonate level decreases but still indicative of metabolic
acidosis
        C0(HCO3) = C0(HCO3) * 0.85;

    case 'htn'
        % Slight decrease to reflect vascular damage
        snGFR = snGFR * 0.90;
end

% Outputs
conc_out = C0;
snGFR_out = snGFR;

end


% Main Code
% -----------------------------
% BASELINE INLET CONCENTRATIONS
% Inlet filtrate concentrations at renal corpuscle, as INPUT into main
function

% Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine, Ca2+
C0 = [140.0000, 102.0000, 5.714, 4.6905, 4.3500, 24.0000, 0.8225, 0.3950,
0.0920, 0.5700]; % mmol/L

% Filtrate into RC/Bowman's capsule for a healthy kidney
% A healthy kidney has a single-nephron GFR of approximately 79 +/- 42
nanoliters per minute (nL/min)
snGFR = 79 / 1000; % nL/min * 1e-3 = mL/min (filtrate into RC/Bowman's
capsule for a healthy kidney)

% Healthy
[C0_h, sn_h] = test_cases(C0, snGFR, 'healthy');
kidney_model(C0_h, sn_h, "Healthy");

% CKD3b
[C0_ckd, sn_ckd] = test_cases(C0, snGFR, 'ckd3b');
kidney_model(C0_ckd, sn_ckd, "CKD3b");
```

```
% T2DM Early
[C0_dme, sn_dme] = test_cases(C0, snGFR, 't2dm_early');
kidney_model(C0_dme, sn_dme, "T2DM (Early)");

% T2DM Late
[C0_dml, sn_dml] = test_cases(C0, snGFR, 't2dm_late');
kidney_model(C0_dml, sn_dml, "T2DM (Late)");

% Hypertension
[C0_htn, sn_htn] = test_cases(C0, snGFR, 'htn');
kidney_model(C0_htn, sn_htn, "Hypertension");

% Combination of all 3, modeling severe CKD
[C0_tmp,  sn_tmp]  = test_cases(C0, snGFR, 'ckd3b');
[C0_tmp,  sn_tmp]  = test_cases(C0_tmp, sn_tmp, 'htn');
[C0_combo, sn_combo] = test_cases(C0_tmp, sn_tmp, 't2dm_late');
kidney_model(C0_combo, sn_combo, "CKD3b + HTN + T2DM (Late)");
```

```
Healthy
--------------------------
8x10 Molar Flow Rate Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
Ca2+  Columns 1 through 7

    0.0111    0.0081    0.0005    0.0004    0.0003    0.0019    0.0001
    0.0074    0.0054    0.0005    0.0000    0.0003    0.0004    0.0001
    0.0050    0.0036    0.0005    0.0000    0.0003    0.0003    0.0001
    0.0039    0.0028    0.0002    0.0000    0.0001    0.0003    0.0001
    0.0039    0.0028    0.0003    0.0000    0.0001    0.0003    0.0001
    0.0029    0.0021    0.0003    0.0000    0.0001    0.0003    0.0000
    0.0028    0.0020    0.0003    0.0000    0.0001    0.0003    0.0000
    0.0028    0.0020    0.0003    0.0000    0.0001    0.0003    0.0000

  Columns 8 through 10

    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000

8x10 Concentrations Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
Ca2+  Columns 1 through 7

  140.0000  102.0000    5.7140    4.6905    4.3500   24.0000    0.8225
```

```
    0.0938    0.0683    0.0057    0.0005    0.0043    0.0048    0.0008
    0.0630    0.0459    0.0057    0.0004    0.0043    0.0043    0.0008
    0.0490    0.0357    0.0029    0.0004    0.0017    0.0043    0.0007
    0.0490    0.0357    0.0033    0.0004    0.0017    0.0037    0.0007
    0.0368    0.0268    0.0033    0.0004    0.0013    0.0037    0.0002
    0.0349    0.0255    0.0033    0.0004    0.0014    0.0035    0.0002
    0.0349    0.0255    0.0033    0.0004    0.0016    0.0035    0.0002

  Columns 8 through 10

    0.3950    0.0920    0.5700
    0.0003    0.0001    0.0004
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0002
    0.0002    0.0001    0.0002
    0.0002    0.0001    0.0002

Outlet (collecting duct) in grams/min per solute:
Na^+: 6.3458e-05
Cl^-: 7.13e-05
Urea: 1.5588e-05
Glucose: 6.0749e-06
K^+: 4.8773e-06
HCO_3^-: 1.6816e-05
Mg^{2+}: 3.6008e-07
PO_4^{3-}: 1.2353e-06
Creatinine: 1.0688e-06
Ca^{2+}: 5.4163e-07


CKD3b
--------------------------
8x10 Molar Flow Rate Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
Ca2+  Columns 1 through 7

    0.0039    0.0028    0.0002    0.0001    0.0001    0.0006    0.0000
    0.0026    0.0019    0.0002    0.0000    0.0001    0.0001    0.0000
    0.0018    0.0013    0.0002    0.0000    0.0001    0.0001    0.0000
    0.0014    0.0010    0.0001    0.0000    0.0001    0.0001    0.0000
    0.0014    0.0010    0.0001    0.0000    0.0001    0.0001    0.0000
    0.0010    0.0007    0.0001    0.0000    0.0000    0.0001    0.0000
    0.0010    0.0007    0.0001    0.0000    0.0000    0.0001    0.0000
    0.0010    0.0007    0.0001    0.0000    0.0001    0.0001    0.0000

  Columns 8 through 10

    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
```

```
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000

8x10 Concentrations Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
Ca2+  Columns 1 through 7

  140.0000  102.0000    7.9996    4.6905    5.0025   21.6000    0.8225
    0.0938    0.0683    0.0080    0.0005    0.0050    0.0043    0.0008
    0.0630    0.0459    0.0080    0.0004    0.0050    0.0039    0.0008
    0.0490    0.0357    0.0040    0.0004    0.0020    0.0039    0.0007
    0.0490    0.0357    0.0046    0.0004    0.0020    0.0033    0.0007
    0.0368    0.0268    0.0046    0.0004    0.0015    0.0033    0.0002
    0.0349    0.0255    0.0046    0.0004    0.0017    0.0031    0.0002
    0.0349    0.0255    0.0046    0.0004    0.0018    0.0031    0.0002

  Columns 8 through 10

    0.4938    0.1472    0.5130
    0.0003    0.0001    0.0003
    0.0002    0.0002    0.0003
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002

Outlet (collecting duct) in grams/min per solute:
Na^+: 2.2361e-05
Cl^-: 2.5125e-05
Urea: 7.6901e-06
Glucose: 2.1407e-06
K^+: 1.9765e-06
HCO_3^-: 5.3331e-06
Mg^{2+}: 1.2688e-07
PO_4^{3-}: 5.441e-07
Creatinine: 6.026e-07
Ca^{2+}: 1.7177e-07


T2DM (Early)
--------------------------
8x10 Molar Flow Rate Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
Ca2+  Columns 1 through 7

    0.0124    0.0091    0.0005    0.0006    0.0004    0.0021    0.0001
    0.0083    0.0061    0.0005    0.0001    0.0004    0.0004    0.0001
    0.0056    0.0041    0.0005    0.0001    0.0004    0.0004    0.0001
    0.0044    0.0032    0.0003    0.0001    0.0002    0.0004    0.0001
```

```
    0.0044    0.0032    0.0003    0.0001    0.0002    0.0003    0.0001
    0.0033    0.0024    0.0003    0.0001    0.0001    0.0003    0.0000
    0.0031    0.0023    0.0003    0.0001    0.0001    0.0003    0.0000
    0.0031    0.0023    0.0003    0.0001    0.0001    0.0003    0.0000

  Columns 8 through 10

    0.0000    0.0000    0.0001
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000
    0.0000    0.0000    0.0000

8x10 Concentrations Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
Ca2+  Columns 1 through 7

  140.0000  102.0000    5.7140    7.0000    4.3500   24.0000    0.8225
    0.0938    0.0683    0.0057    0.0007    0.0043    0.0048    0.0008
    0.0630    0.0459    0.0057    0.0006    0.0043    0.0043    0.0008
    0.0490    0.0357    0.0029    0.0006    0.0017    0.0043    0.0007
    0.0490    0.0357    0.0033    0.0006    0.0017    0.0037    0.0007
    0.0368    0.0268    0.0033    0.0006    0.0013    0.0037    0.0002
    0.0349    0.0255    0.0033    0.0006    0.0014    0.0035    0.0002
    0.0349    0.0255    0.0033    0.0006    0.0016    0.0035    0.0002

  Columns 8 through 10

    0.3950    0.0920    0.5700
    0.0003    0.0001    0.0004
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0002
    0.0002    0.0001    0.0002
    0.0002    0.0001    0.0002

Outlet (collecting duct) in grams/min per solute:
Na^+: 7.139e-05
Cl^-: 8.0212e-05
Urea: 1.7537e-05
Glucose: 1.0199e-05
K^+: 5.4869e-06
HCO_3^-: 1.8918e-05
Mg^{2+}: 4.0508e-07
PO_4^{3-}: 1.3897e-06
Creatinine: 1.2024e-06
Ca^{2+}: 6.0933e-07
```

T2DM (Late)

8x10 Molar Flow Rate Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine, Ca2+ Columns 1 through 7

0.0023	0.0017	0.0001	0.0002	0.0001	0.0003	0.0000
0.0016	0.0011	0.0001	0.0000	0.0001	0.0001	0.0000
0.0010	0.0008	0.0001	0.0000	0.0001	0.0001	0.0000
0.0008	0.0006	0.0000	0.0000	0.0000	0.0001	0.0000
0.0008	0.0006	0.0001	0.0000	0.0000	0.0001	0.0000
0.0006	0.0004	0.0001	0.0000	0.0000	0.0001	0.0000
0.0006	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000
0.0006	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000

Columns 8 through 10

0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000

8x10 Concentrations Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine, Ca2+ Columns 1 through 7

140.0000	102.0000	5.7140	9.7000	5.6550	20.4000	0.8225
0.0938	0.0683	0.0057	0.0010	0.0057	0.0041	0.0008
0.0630	0.0459	0.0057	0.0009	0.0057	0.0037	0.0008
0.0490	0.0357	0.0029	0.0009	0.0023	0.0037	0.0007
0.0490	0.0357	0.0033	0.0009	0.0023	0.0031	0.0007
0.0368	0.0268	0.0033	0.0009	0.0017	0.0031	0.0002
0.0349	0.0255	0.0033	0.0009	0.0019	0.0030	0.0002
0.0349	0.0255	0.0033	0.0009	0.0021	0.0030	0.0002

Columns 8 through 10

0.4542	0.0920	0.5700
0.0003	0.0001	0.0004
0.0002	0.0001	0.0003
0.0002	0.0001	0.0003
0.0002	0.0001	0.0003
0.0002	0.0001	0.0002
0.0002	0.0001	0.0002
0.0002	0.0001	0.0002

Outlet (collecting duct) in grams/min per solute:
Na^+: 1.3296e-05

Cl^-: 1.4939e-05
Urea: 3.2661e-06
Glucose: 2.6322e-06
K^+: 1.3285e-06
HCO_3^-: 2.9949e-06
Mg^{2+}: 7.5444e-08
PO_4^{3-}: 2.9764e-07
Creatinine: 2.2394e-07
Ca^{2+}: 1.1348e-07

Hypertension

8x10 Molar Flow Rate Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine, Ca2+ Columns 1 through 7

0.0100	0.0073	0.0004	0.0003	0.0003	0.0017	0.0001
0.0067	0.0049	0.0004	0.0000	0.0003	0.0003	0.0001
0.0045	0.0033	0.0004	0.0000	0.0003	0.0003	0.0001
0.0035	0.0025	0.0002	0.0000	0.0001	0.0003	0.0000
0.0035	0.0025	0.0002	0.0000	0.0001	0.0003	0.0000
0.0026	0.0019	0.0002	0.0000	0.0001	0.0003	0.0000
0.0025	0.0018	0.0002	0.0000	0.0001	0.0002	0.0000
0.0025	0.0018	0.0002	0.0000	0.0001	0.0002	0.0000

Columns 8 through 10

0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000

8x10 Concentrations Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine, Ca2+ Columns 1 through 7

140.0000	102.0000	5.7140	4.6905	4.3500	24.0000	0.8225
0.0938	0.0683	0.0057	0.0005	0.0043	0.0048	0.0008
0.0630	0.0459	0.0057	0.0004	0.0043	0.0043	0.0008
0.0490	0.0357	0.0029	0.0004	0.0017	0.0043	0.0007
0.0490	0.0357	0.0033	0.0004	0.0017	0.0037	0.0007
0.0368	0.0268	0.0033	0.0004	0.0013	0.0037	0.0002
0.0349	0.0255	0.0033	0.0004	0.0014	0.0035	0.0002
0.0349	0.0255	0.0033	0.0004	0.0016	0.0035	0.0002

Columns 8 through 10

```
    0.3950    0.0920    0.5700
    0.0003    0.0001    0.0004
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0003
    0.0002    0.0001    0.0002
    0.0002    0.0001    0.0002
    0.0002    0.0001    0.0002

Outlet (collecting duct) in grams/min per solute:
Na^+: 5.7112e-05
Cl^-: 6.417e-05
Urea: 1.4029e-05
Glucose: 5.4674e-06
K^+: 4.3896e-06
HCO_3^-: 1.5135e-05
Mg^{2+}: 3.2407e-07
PO_4^{3-}: 1.1117e-06
Creatinine: 9.6192e-07
Ca^{2+}: 4.8747e-07


CKD3b + HTN + T2DM (Late)
--------------------------
8x10 Molar Flow Rate Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
Ca2+   1.0e-03 *

  Columns 1 through 7

    0.7349    0.5354    0.0420    0.0509    0.0341    0.0964    0.0043
    0.4924    0.3587    0.0420    0.0051    0.0341    0.0193    0.0043
    0.3309    0.2411    0.0420    0.0046    0.0341    0.0173    0.0043
    0.2574    0.1876    0.0210    0.0046    0.0137    0.0173    0.0035
    0.2574    0.1876    0.0241    0.0046    0.0137    0.0147    0.0035
    0.1931    0.1407    0.0241    0.0046    0.0102    0.0147    0.0010
    0.1834    0.1336    0.0241    0.0046    0.0113    0.0140    0.0010
    0.1834    0.1336    0.0241    0.0046    0.0124    0.0140    0.0010

  Columns 8 through 10

    0.0030    0.0008    0.0027
    0.0019    0.0008    0.0018
    0.0015    0.0010    0.0013
    0.0013    0.0010    0.0012
    0.0013    0.0010    0.0012
    0.0013    0.0010    0.0009
    0.0012    0.0010    0.0009
    0.0012    0.0010    0.0008

8x10 Concentrations Matrix
• Rows = RC, S1, S2, S3, DL, AL, DT, CD
• Columns = Na+, Cl-, Urea, Glucose, K+, HCO3-, Mg2+, PO4^3-, Creatinine,
```

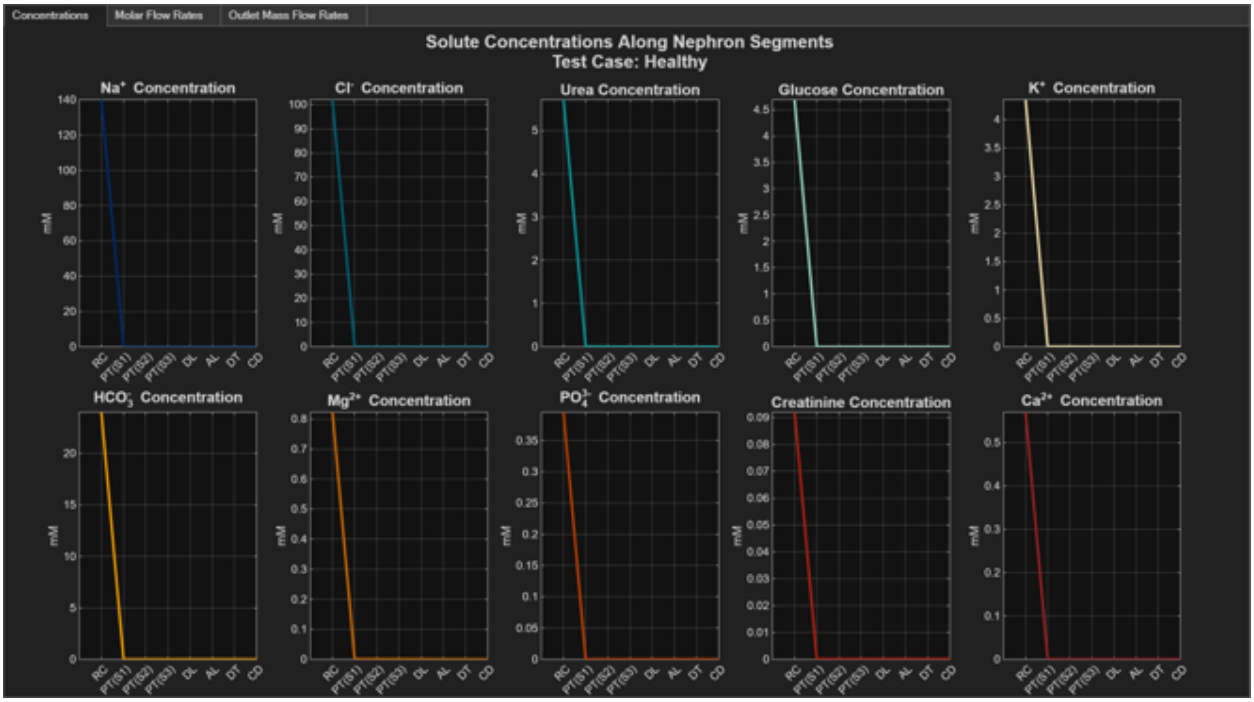
```
Ca2+  Columns 1 through 7

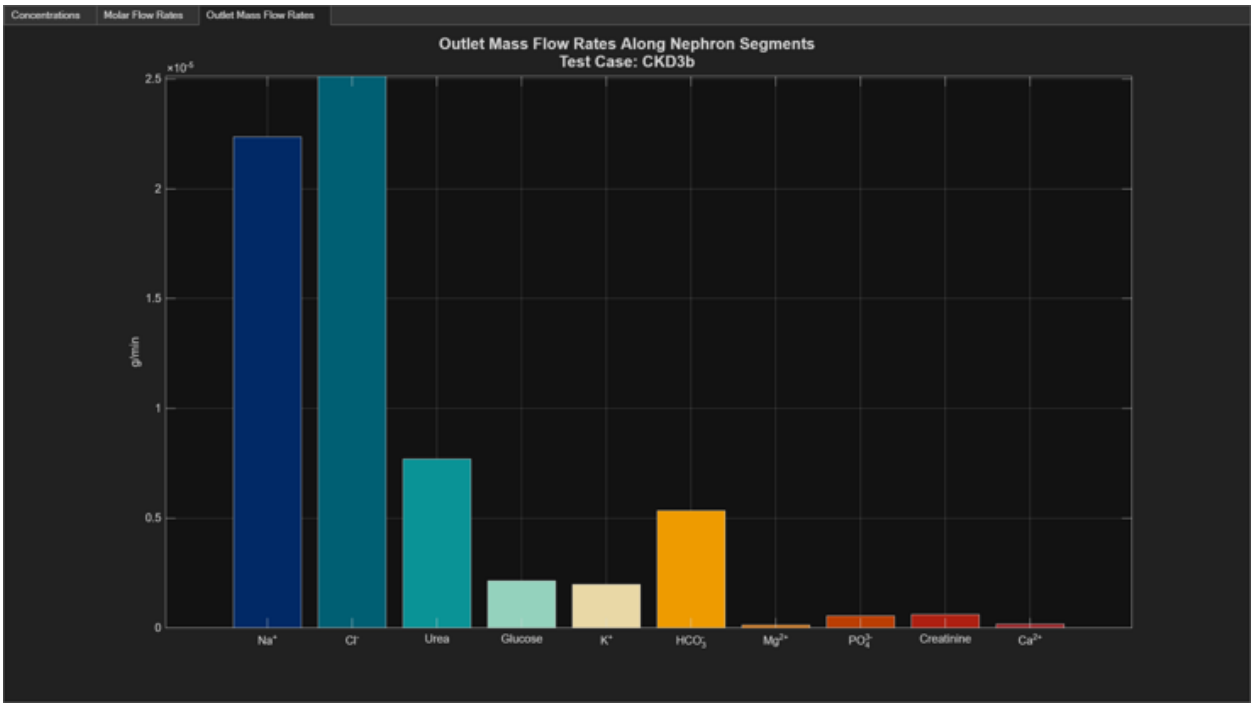
  140.0000  102.0000    7.9996    9.7000    6.5032   18.3600    0.8225
    0.0938    0.0683    0.0080    0.0010    0.0065    0.0037    0.0008
    0.0630    0.0459    0.0080    0.0009    0.0065    0.0033    0.0008
    0.0490    0.0357    0.0040    0.0009    0.0026    0.0033    0.0007
    0.0490    0.0357    0.0046    0.0009    0.0026    0.0028    0.0007
    0.0368    0.0268    0.0046    0.0009    0.0020    0.0028    0.0002
    0.0349    0.0255    0.0046    0.0009    0.0021    0.0027    0.0002
    0.0349    0.0255    0.0046    0.0009    0.0024    0.0027    0.0002

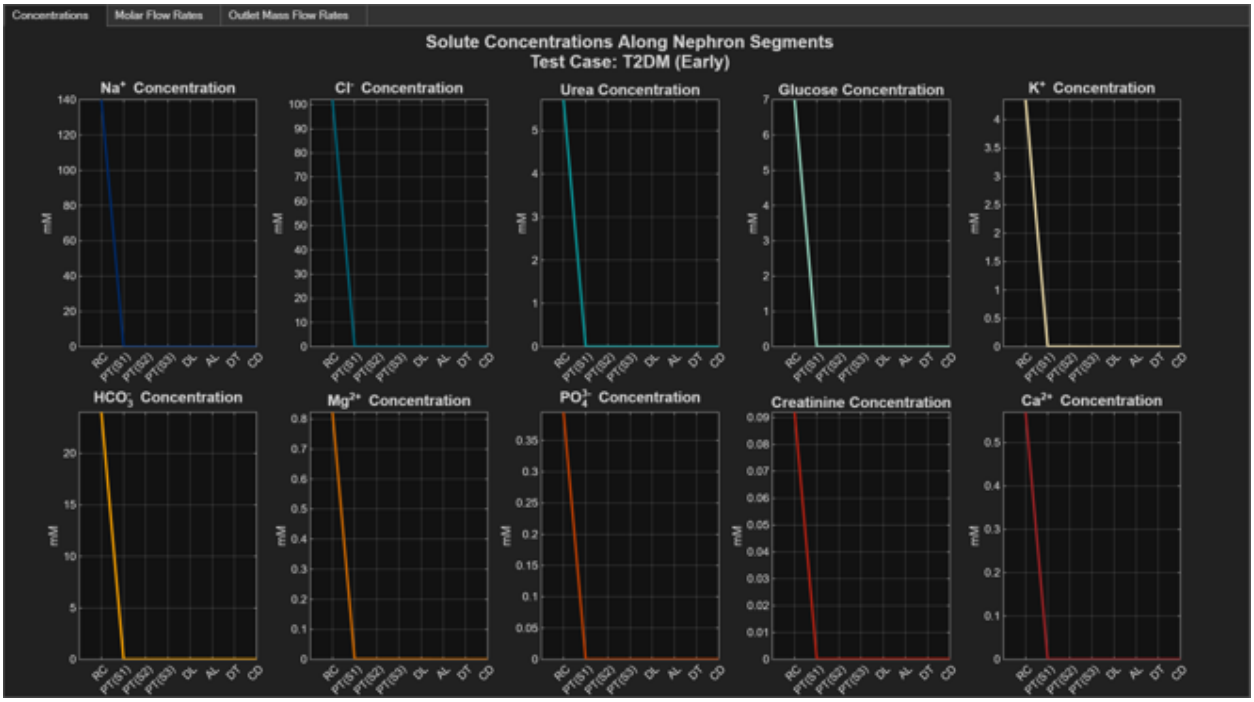
  Columns 8 through 10

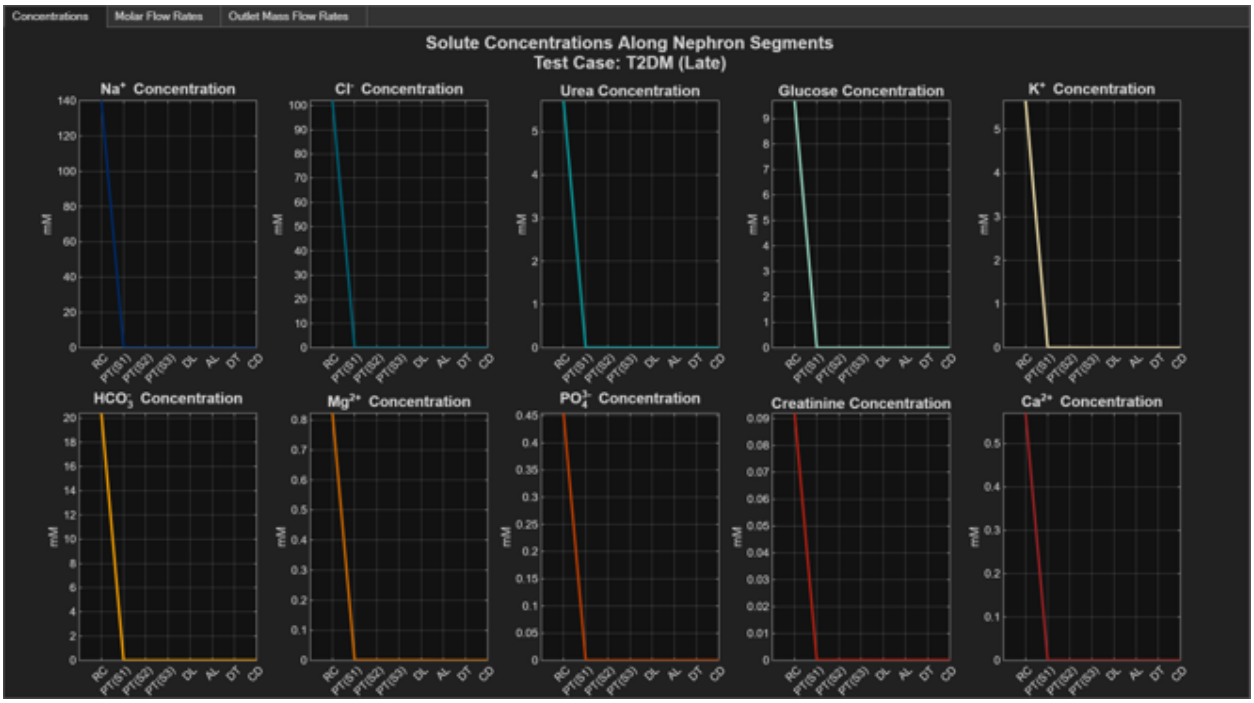
    0.5678    0.1472    0.5130
    0.0004    0.0001    0.0003
    0.0003    0.0002    0.0003
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002
    0.0002    0.0002    0.0002

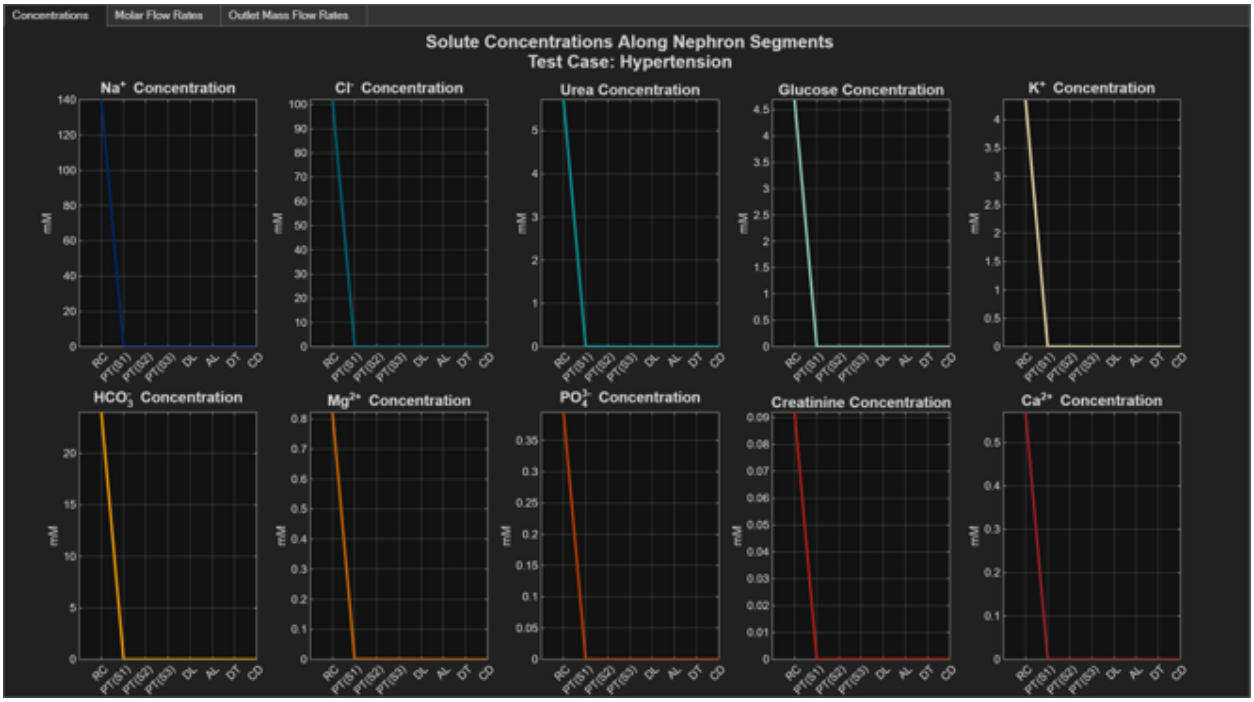
Outlet (collecting duct) in grams/min per solute:
Na^+: 4.2167e-06
Cl^-: 4.7378e-06
Urea: 1.4501e-06
Glucose: 8.3479e-07
K^+: 4.8451e-07
HCO_3^-: 8.5482e-07
Mg^{2+}: 2.3927e-08
PO_4^{3-}: 1.1799e-07
Creatinine: 1.1363e-07
Ca^{2+}: 3.2392e-08
```

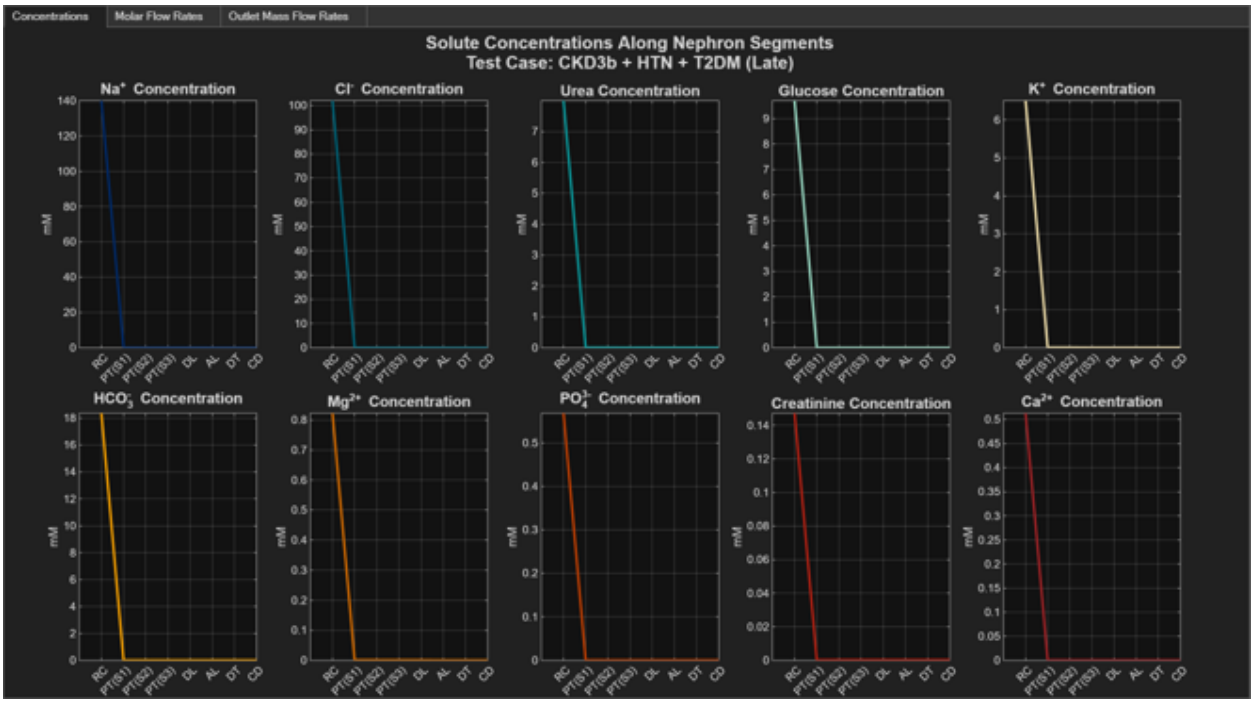

Concentrations
Molar Flow Rates
Outlet Mass Flow Rates
Solute Concentrations Along Nephron Segments
Test Case: Healthy
Na⁺ Concentration
Cl⁻ Concentration
Urea Concentration
Glucose Concentration
K⁺ Concentration
HCO3⁻ Concentration
Mg2+ Concentration
PO4 3- Concentration
Creatinine Concentration
Ca2+ Concentration
mM
RC
PT(S1)
PT(S2)
PT(S3)
DL
AL
DT
CD


Concentrations
Molar Flow Rates
Outlet Mass Flow Rates
Outlet Mass Flow Rates Along Nephron Segments
Test Case: CKD3b
×10⁻⁶
g/min
Na⁺
Cl⁻
Urea
Glucose
K⁺
HCO3⁻
Mg2+
PO4 3-
Creatinine
Ca2+


Concentrations
Molar Flow Rates
Outlet Mass Flow Rates
Solute Concentrations Along Nephron Segments
Test Case: T2DM (Early)
Na⁺ Concentration
Cl⁻ Concentration
Urea Concentration
Glucose Concentration
K⁺ Concentration
HCO3⁻ Concentration
Mg2+ Concentration
PO4 3- Concentration
Creatinine Concentration
Ca2+ Concentration
mM
RC
PT(S1)
PT(S2)
PT(S3)
DL
AL
DT
CD


Concentrations
Molar Flow Rates
Outlet Mass Flow Rates
Solute Concentrations Along Nephron Segments
Test Case: T2DM (Late)
Na⁺ Concentration
Cl⁻ Concentration
Urea Concentration
Glucose Concentration
K⁺ Concentration
HCO3⁻ Concentration
Mg2+ Concentration
PO4 3- Concentration
Creatinine Concentration
Ca2+ Concentration
mM
RC
PT(S1)
PT(S2)
PT(S3)
DL
AL
DT
CD





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